On Turbulent Pressure Confinement of Ultra-Compact HII Regions

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ABSTRACT

It has been proposed recently that the small size and long lifetime of ultracompact (UC) HII regions could be due to pressure confinement if the thermal pressure of the ambient gas is higher than previous estimates. We point out that confinement by thermal pressure alone implies emission measures in excess of observed values. We show that turbulent pressure, inferred from observed non-thermal velocities, is sufficient to confine UC HII regions and explain their longevity. We predict an anti-correlation between the size of UC HII regions and the velocity dispersion of the ambient neutral gas, and show that it is consistent with existing observations.

Subject headings: ISM: HII regions—ISM: kinematics and dynamics—stars: formation—turbulence

1. INTRODUCTION

Ultracompact HII regions (UCHII's) are very small (< 0.2 pc) dense regions of ionized gas in molecular clouds first noted by Ryle & Downes (1967) and Dreher & Welch (1981). Deeply embedded, the ionized gas is seen only through free-free emission at radio wavelengths. The importance of this type of object for our understanding of the birth of massive stars is well recognized (Churchwell 1993; Welch 1993; Vogel 1994). A key unsettled

question is the discrepancy between the characteristic age ($\sim 10^5\ yr$) of UC HIIs implied by their ubiquity (Wood & Churchwell 1989, hereafter WC89; Kurtz, Churchwell & Wood 1994, hereafter KCW94) and the very short dynamical lifetime ($\sim 10^3\ yr$) estimated from the sound crossing time. This disparity implies the presence of physical mechanisms which confine the UC HIIs. Proposed possibilities include: (1) ram pressure due to gravitational infall of ambient gas onto the HII region (cf. Reid et al 1981; Dreher & Welch 1981; Ho & Haschick 1986), (2) stellar wind bow shock/ram pressure confinement (cf. WC89; van Buren et al 1990), and (3) photo-evaporating disks (Vogel, Genzel & Palmer 1987; Welch 1993; Hollenbach et al 1994) or photo-evaporating clumps (Lizano & Cantó 1995; Williams et al 1996), or champagne-flow/blisters (Tenorio-Tagle 1979; Yorke et al 1983; Forster et al 1990).

2. CONFINEMENT BY THERMAL PRESSURE

De Pree et al (1995) (see also García-Segura & Franco 1996 and Akeson & Carlstrom 1996) have recently suggested that the compactness of the UC HIIs can be explained if the density and temperature in the ambient neutral gas are much higher than commonly assumed. Their basic argument is two-fold. First, the initial Strömgren radius R_S scales inversely with gas density (e.g. Spitzer 1978) as

$$R_S = (\frac{3S_*}{4\pi\beta_2})^{1/3} n_0^{-2/3} = 1.99\times 10^{-2} (\frac{S_*}{10^{49}\ s^{-1}})^{1/3} (\frac{n_{H2}}{10^5\ cm^{-3}})^{-2/3}\ pc, \tag{1}$$

where S_* is the flux of ionizing photons, $n_0 = 2n_{H_2}$ is the initial electron density in the ionized gas and $\beta_2 = 2.6\times 10^{-13}\ cm^3\ s^{-1}$ is the recombination coefficient. Thus, for a sufficiently high ambient molecular density, the initial Strömgren sphere can be very small. Second, a higher ambient gas temperature reduces the amount that the ionized gas expands before reaching pressure equilibrium with the ambient material.

The emission measure of the ionized gas predicted by this simple scenario, however, is significantly larger than the values generally observed. This point can be verified easily from the calculations and discussions by De Pree et al (1995). For a sample of small UC HIIs, De Pree et al showed that an ambient molecular density of $10^7\ cm^{-3}$ together with a gas temperature of $\sim 200\ K$ would suffice to explain the compactness of the UC HIIs. They estimated an initial Strömgren radius $R_S = 1.0\times 10^{-3}\ pc$ at such high density, corresponding to an initial emission measure $EM_0 = 2n_0^2 R_S = 8\times 10^{11}\ cm^{-6}\ pc$. Overpressured, the initial ionized sphere expands outward until it reaches pressure equilibrium with ambient neutral

gas. At a later time, when the ionized sphere has a radius R and electron density n_e, the emission measure will drop to

$$EM = 2n_e^2 R = (\frac{R_S}{R})^2 EM_0. \tag{2}$$

For $R = 0.01\ pc$, the emission measure is thus expected to be $\sim 8 \times 10^9\ cm^{-6}\ pc$. The observed average emission measures for spherical UC HII regions with sizes $\sim 0.01\ pc$ are mostly around a few $\times 10^7$ to a few $\times 10^8\ cm^{-6}\ pc$ in the WC89 and KCW94 surveys, lower than the predicted value by over an order of magnitude, although there clearly are some UC HIIs which have very high emission measures (cf. Turner & Matthews 1984; Garay et al 1993a). It seems unlikely that the assumption of optical thinness for the radio emission could have underestimated the emission measure by such a large factor. Therefore, although the gas density around some UC HIIs is indeed higher than $10^5\ cm^{-3}$ (the density originally adopted by WC89) as recent observations have revealed (cf. Huttemeister et al 1993; Akeson & Carlstrom 1996; Plume et al 1996), a gas density of $n_{H_2} = 10^7\ cm^{-3}$ as adopted by De Pree et al (1995) seem too high for the material around typical spherical UC HIIs with $R \sim 0.01\ pc$ in WC89 and KCW94 surveys. Other physical processes such as swept-up shells or dust absorption of Lyman photons may modify the predicted emission measure somewhat, but it is not difficult to see that the former would further increase the emission measure, while the latter can only reduce the emission measure by a factor of $(1-x)^{1/3}$, where x is the fraction of Lyman photons absorbed by dust grains (Franco et al 1990; Churchwell 1993). For $x = 0.9$, the emission measure is reduced by a factor of 0.46 (WC89). While not necessarily irrelevant, dust absorption alone is not likely to be able to account for the observed low emission measure for a significant fraction of UC HIIs. We conclude that confinement by thermal pressure requires UC HIIs to have higher emission measures than observed in most cases.

3. TURBULENT PRESSURE CONFINEMENT

3.1. Plausibility

That the gas pressure in the interstellar medium is not limited to the thermal pressure alone is evident from emission line profiles and has recently been brought up in connection with UC HIIs by García-Segura & Franco (1996). Ever since the discovery of molecular clouds, it has been known that the Doppler-broadened line profiles of all molecular tracers

indicate the presence of significant non-thermal motions, referred to as turbulence, down to the smallest scales probed even for low mass molecular structures (cf. Falgarone, Puget & Pérault 1992). Since massive star forming regions are well-known to have stronger turbulence (cf. Plume et al 1996), it is likely that turbulence exists ubiquitously on the scales of UCHIIs. Regardless of whether the origin is hydrodynamic or hydromagnetic, the presence of turbulence implies a significant pressure in addition to the thermal pressure. Massive star forming regions, where UC HIIs are found, are particularly turbulent, often with velocity dispersions well in excess of a couple of kilometers per second (Cesaroni et al 1991; hereafter CWKC; Plume et al 1996). The turbulent pressure implied is considerably larger than the thermal pressure. For example, the turbulent pressure $P = n_{H_2} m_{H_2} \sigma_v^2$ corresponding to a velocity dispersion of $\sigma_v = 2\ km\ s^{-1}$ is equivalent to a thermal pressure at an effective kinetic temperature of $T_{eff} \sim 10^3\ K$. In fact, if massive star forming cores where UC HIIs reside are indeed close to virial equilibrium (CWKC), the implied molecular gas pressure ought to be comparable to the ram pressure due to free-fall collapse. Therefore, as long as turbulence exists down to the scales of UCHIIs, it seems safe to conclude that turbulent pressure could provide significant opposition to the expansion of the ionized gas, just as would the ram pressure due to gravitational collapse of the molecular envelope (Reid et al 1981).

The validity of the above hypothesis can be clarified by further considering the two conceptual phases of UC HII development (Dyson & Williams 1980; WC89). The first phase, i.e., the establishment of an initial Strömgren sphere, is not affected much by the turbulence, so the general results and conclusions in Dyson & Williams (1980) and WC89 remain valid, and the Strömgren sphere with radius determined by Equation (1) will form in a matter of a few years [1]. The temperature of the newly ionized gas jumps to $T_{H^+} \sim 10^4\ K$ and the number density of the particles in the gas increases by roughly a factor of 4 due to dissociation and ionization. This, together with the ram pressure due to stellar winds, causes the ionized gas to expand outward at its sound velocity until reaching approximate pressure equilibrium with the ambient molecular gas. Instead of completely neglecting the pressure due to stellar winds and turbulence in the ionized gas (Dyson & Williams 1980; De Pree et al 1995), we introduce a factor ξ (> 1) to partially take them into account (It can be argued that the ram pressure due to stellar winds may be reflected by an enhanced actual electron density in a swept-up shell). The final average electron density n_e in the HII region can then be estimated from the following condition (Dyson & Williams 1980; WC89),

$$2\xi n_e k T_{H^+} = n_{H_2}(m_{H_2}\sigma_v^2 + kT_k) = n_{H_2} m_{H_2} \delta v_{tot}^2/(8ln2), \tag{3}$$

[1] Note that a uniform density is assumed.

where T_k is the molecular gas kinetic temperature and $\delta v_{tot} = (8ln2)^{1/2}(\sigma_v^2 + \frac{k}{m_{H_2}}T_k)^{1/2}$ is the FWHM of an optically-thin molecular line tracing the high density gas around the UC HIIs. δv_{tot} includes both non-thermal and thermal components. If S_*, the flux of ionizing photons, remains largely unchanged during the expansion and the HII region is ionization-bounded, one has

$$S_*(1-x) = \frac{4}{3}\pi R^3 n_e^2 \beta_2 = \frac{4}{3}\pi R_S^3 n_0^2 \beta_2. \quad (4)$$

Equations (3) and (4) give

$$R = R_S(\frac{4k\xi T_{H^+}}{m_{H_2}\sigma_v^2 + kT_k})^{2/3} = R_S(\frac{32ln2k\xi T_{H^+}}{m_{H_2}\delta v_{tot}^2})^{2/3}. \quad (5)$$

So, turbulent pressure can significantly reduce the final equilibrium size of the UC HII region. If $\sigma_v = 2\ km\ s^{-1}$ and $T_k \simeq 100\ K$, we have $R = 9.54\xi^{2/3}R_S$ (versus $R = 54.3R_S$ with thermal pressure alone). For $n_{H_2} = 8 \times 10^5\ cm^{-3}$ and $S_* = 10^{49}\ s^{-1}$ (for O6 star), we have $R_S = 0.005(1-x)^{1/3}\ pc$ and $EM_0 = 2.5 \times 10^{10}(1-x)^{1/3}\ cm^{-6}pc$. Thus $EM = (\frac{R_S}{R})^2 EM_0 = 2.8 \times 10^8 \xi^{-4/3}(1-x)^{1/3}\ cm^{-6}pc$ and $R = 0.05\xi^{2/3}(1-x)^{1/3}\ pc$. For reasonable dust absorption coefficient x and factor ξ, both the predicted size and emission measure are reasonable in comparison with those inferred from observations (WC89; KCW94), especially considering the expected variation in n_{H_2}, S_* and δv_{tot} from region to region. In particular, it appears that the initial Strömgren sphere expands by a factor of ~ 10, say from $\sim 0.01\ pc$ to $\sim 0.1\ pc$, before reaching pressure equilibrium with the turbulent ambient molecular gas. The time for the expansion can be roughly estimated from the sound crossing time, $\tau_{expansion} \sim \frac{R}{C_s} \sim 10^4\ yr$, where C_s is the sound speed in ionized gas taken as $10\ km\ s^{-1}$. Since the average age of the UC HIIs observed is close to $10^5\ yr$ (WC89; KCW94), most UC HIIs might indeed have had enough time to expand to reach pressure equilibrium with their ambient molecular gas (cf. García-Segura & Franco 1996).

Note that this scenario, just as the classic picture for HII regions, predicts that HII regions with larger sizes will have a lower average electron density. This is consistent with observations by Garay et al (1993b), Churchwell (1993) and KCW94. Such a size-density correlation is somewhat less obvious for UC HIIs with cometary and core-halo morphologies (KCW94; Churchwell 1993). But it is somewhat difficult to define the average electron density for non-spherical UC HIIs and thus the determined densities for these sources in the literature are likely subject to relatively large systematic errors (Stan Kurtz 1996, private communication). Further careful observational studies on this aspect will be useful.

3.2. Velocity Dispersion-UC HII Size Relation

Equation (5) indicates that the size of UC HIIs ought to be anti-correlated with the total gas pressure or velocity dispersion of the ambient molecular gas if the gas pressure is indeed responsible for the compactness of UC HIIs. In the case that R_S (i.e., S_*) does not vary much from one region to another, Equation (5) predicts $\delta v_{tot} \propto D_{UC}^{-3/4}$. However, the surveys by WC89, Garay et al (1993b) and KCW94 imply that S_* has a strong dependence on R in the sense that larger UCHIIs tend to have a larger ionizing flux S_* (Churchwell & Kurtz 1996, private communication) [2]. Assuming that the HIIs are ionization-bounded, the $S_* - R$ dependence can be derived from the proposed $n_e - R$ relation, $n_e = n_{e0.1pc}(\frac{R}{0.1\,pc})^{-\alpha}$, where $n_{e0.1pc}$ is the average electron density for UCHIIs with $R = 0.1pc$. Therefore, $S_*(1-x) = \frac{4}{3}\pi R^3 n_e^2 \beta_2 \propto R^{3-2\alpha}$, and we have

$$\delta v_{tot} = (\frac{16ln2kT_{H^+}}{m_{H_2}})^{1/2}(\frac{\xi n_{e0.1pc}}{n_{H_2}})^{1/2}(\frac{R}{0.1pc})^{-\alpha/2}. \qquad (6)$$

Churchwell (1993) and KCW94 found that $\alpha \sim 0.65$ provides a reasonable fit to their data for a sample of spherical and unresolved UCHIIs, while Garay et al (1993b) preferred $\alpha \sim 0.98$ for a larger sample of HIIs with various morphological types, some of which have relatively large sizes.

While the size of the UC HIIs can be determined easily from the VLA maps, it is not entirely trivial to obtain δv_{tot} observationally. Specifically, the following criteria must be considered in choosing molecular lines for a reliable determination of δv_{tot}. First, the molecular line used must have a relatively high critical excitation density in order to sample the dense gas in the immediate neighborhood of UC HIIs. Second, to reduce foreground and background confusion as well as line broadening by optical depth effects, the molecular line must be optically thin. Third, the spatial and spectral resolutions must be adequate. Existing systematic surveys of molecular gas associated with UC HIIs using lower transitions of ammonia and CO and isotopes can be immediately ruled out by the above criteria. At this time, it appears that the $C^{34}S$ survey of 8 UC HIIs by CWKC with the IRAM 30m telescope is the only systematic data set in the literature from which δv_{tot} can be determined reasonably well for a non-biased sample of UC HIIs. Among the 3 transitions of $C^{34}S$ observed, the $J = 2-1$ data with a spatial resolution of 25" is preferred based on considerations of its optical thinness, superior velocity resolution and reliable detection in all cases. Higher transitions show significantly larger linewidths, indicating possible additional broadening due to other physical processes such as optical depth effects, and outflows.

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[2]If S_* does not vary much from region to region, one expects to see a steep $n_e - R$ relation, $n_e \propto R^{-1.5}$. In reality, such steep $n_e - R$ dependence is not seen (Churchwell 1993; Garay et al 1993b; KCW94)

Figure 1 shows the data points for all 8 UC HIIs observed in $C^{34}S$ $J = 2 - 1$ by CWKC in comparison with the expected correlation for pressure-confined UC HII regions. The dotted, solid and dashed lines represent Equation (6) with $\alpha = 0.65$ (Churchwell 1993; KCW94) for $\frac{\xi n_{e0.1pc}}{n_{H_2}} = 2.55 \times 10^{-2}$, $\frac{\xi n_{e0.1pc}}{n_{H_2}} = 4.04 \times 10^{-2}$ and $\frac{\xi n_{e0.1pc}}{n_{H_2}} = 8.08 \times 10^{-2}$, respectively, i.e. $\delta v_{tot} = (3.16, 2.24, 1.78) D_{UC}^{-0.325}$, where $D_{UC} = 2R$. Despite a large scatter, an anti-correlation between δv_{tot} and D_{UC} is evident and in excellent agreement with the theoretical prediction with $\alpha = 0.65$. In fact, a least-squares-fit to the 8 data points gives $\delta v_{tot}(km\ s^{-1}) = (2.45 \pm 1.17) D_{UC}^{-0.29 \pm 0.07}$ with a correlation coefficient $r = 0.87$, which is almost identical to the solid line. Equation (6) with $\alpha = 0.98$ (Garay et al 1993b) does not fit the 8 data points as well, but it is worth noting again that the Garay et al sample of UC HIIs contains not only larger HIIs but also non-spherical HIIs for which the determined mean electron density is subject to larger uncertainties. Since δv_{tot} does not show any correlation with the distances to these HII regions, the possibility that the above anti-correlation results from the different physical sizes probed by the same telescope beam at different distances appears unlikely. From Churchwell (1993) and KCW94, we have $n_{e0.1pc} \sim 10^4\ cm^{-3}$. Therefore the solid line in Figure 1 implies an average molecular gas density $n_{H_2} \sim 2.5\xi \times 10^5\ cm^{-3}$. Given the uncertainties involved, this implied mean molecular density is in reasonable agreement with the densities derived for these regions (CWKC) and other massive star forming cores (Plume et al 1996), especially considering the fact that some UC HIIs may not reside in the densest molecular gas in massive star forming cores (cf. Churchwell 1993; Hofner et al 1996; Xie et al 1996). Considering the large uncertainty in D_{UC} due to the highly uncertain distances to these regions, the consistency between the observations and the theoretical prediction for $\delta v_{tot} - R$ relation with $\alpha = 0.65$ is surprisingly good.

Finally, we note that δv_{tot} may include systematic motions such as collapse and outflow or expansion, as observations indeed suggest (cf. Ho & Haschick 1986; Peng 1995; Hofner et al 1996; Shepherd & Churchwell 1996; Xie et al 1996). The infall of gas provides additional confining pressure, just like the turbulent motion. In the extreme case that δv_{tot} is largely dominated by outflowing motion, however, there appears an alternative interpretation for the $\delta v_{tot} - D_{UC}$ anti-correlation in the sense that younger and thus smaller UC HIIs may be associated with larger outflowing motions. We feel that this interpretation is less attractive given the interferometric observations which indicate that an UC HII is often just one of a few massive stars in a cluster on a considerably larger scale, and the energy input due to an UC HII alone is unlikely to be dominant (cf. Wilner, Welch & Forster 1995; Xie et al 1996).

4. DISCUSSION

We also note that it would be naive to expect turbulent gas pressure to be the dominant confining mechanism for every UC HII region. A desirable aspect of the simple turbulent pressure confinement idea is that it does not deny the possible role that any other mechanisms may play in addition to the turbulent pressure.

One natural prediction of the turbulent pressure confinement of UC HIIs is that UC HIIs in relatively quiescent molecular clouds must be rare because they will be short-lived. Unfortunately, it is difficult to check this prediction observationally, because it has long been known that massive stars tend to form in massive molecular cloud cores where turbulence is known to be stronger. However, since even an initially quiescent molecular cloud would become turbulent as soon as the first generation of stars form and inject kinetic energy as outflows, one interesting speculation is that the first massive stars may develop larger HII regions around them and trigger the formation of a later generation of stars due to the enhanced gas pressure. The stars of later generations formed in the pressure environment would have to spend considerably longer time embedded in their ambient molecular gas and dust.

Systematic surveys of the molecular gas around a large number of UC HIIs using optically-thin, high density-sensitive molecular lines with resolution on the order of ~ 10" would be highly useful in confirming or rejecting the reality of the proposed velocity dispersion-UCHII size relationship and in clarifying the role that gas pressure plays in the development of HII regions around newly-formed massive stars. More detailed studies of $n_e - R$ or $S_* - R$ relation for UCHIIs of various morphologies and sizes will also be very helpful. In particular, it would be highly desirable if high quality multi-transitional data could be taken for a large number of UC HIIs with a wide range of sizes, which could then be used to determine the density of the molecular gas as well and thus to check if the UC HIIs are indeed in rough pressure equilibrium with ambient molecular gas.

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REFERENCES

Akeson, R.L., & Carlstrom, J.E. 1996, ApJ, in press

Cesaroni, R., Walmsley, C.M., Kömpe, C., & Churchwell, E.B. 1991, AA, 252, 278 (CWKC)

Churchwell, E.B. 1993, in Massive Stars: Their Lives in the ISM, 35

Churchwell, E., Walmsley, C.M., & Wood, D.O.S. 1992, AA 253, 541

De Pree, C.G., Rodríguez, L.F., & Goss, W.M. 1995, RMAA, 31, 39

Dreher, J.W., & Welch, W.J. 1981, ApJ, 245, 857

Dyson, J.E., & Williams, D.A. 1980, Physics of the Interstellar Medium (New York: John Wiley & Sons), 132

Falgarone, E., Puget, J.-L., & Pérault, M. 1992, AA, 257, 715

Forster, J.R., Caswell, J.L., Okumura, S.K., Hasegawa, T., & Ishiguro, M. 1990, AA, 231, 473

Franco, J., Tenorio-Tagle, G., & Bodenheimer, P. 1990, ApJ, 349, 126

Garay, G., Moran, J.M., & Rodríguez, L.F. 1993a, ApJ, 413, 582

Garay, G., Rodríguez, L.F., Moran, J.M., & Churchwell, E. 1993b, ApJ, 418, 368

García-Segura, G., & Franco, J. 1996, preprint

Ho, P.T.P & Haschick, A.D. 1986, ApJ, 304, 501

Hollenbach, D., Johnstone, D., Lizano, S., & Shu, F. 1994, ApJ, 428, 654

Hofner, P., Kurtz, S., Churchwell, E., Walmsley, C.M., & Cesaroni, R. 1996, ApJ, 460, 359

Huttemeister, S., Wilson, T.L., Henkel, C., & Mauersberger, R. 1993,AA, 276, 445

Kurtz, S., Churchwell, E., & Wood, D.O.S. 1994, ApJS, 91, 659 (KCW94)

Lizano, S. & Cantó, J. 1995, RMAA, 1, 29

Peng, Y. 1995, PhD Thesis, University of Maryland at College Park

Plume, R., Jaffe, D.T., Evans II, N.J., Martin-Pintado, J., & Gomez-Gonzalez, J. 1996, ApJ, submitted

Reid, M.J., Haschick, A.D., Burke, B.F., Moran, J.M., Johnston, K.J., & Swenson, G.W., Jr. 1981, ApJ, 239, 89

Ryle, M. & Downes, D. 1967, ApJ, 148, L17

Shepherd, & Churchwell, 1996, ApJ, 457, 267

Spitzer, L. 1978, in Physical Processes in the Interstellar Medium, (New York: Wiley)

Tenorio-Tagle, G. 1979, AA 71, 59

Turner, B.E., & Matthews, H.E. 1984, ApJ, 277, 164

van Buren, D., Mac Low, M.-M., Wood, D.O.S., & Churchwell, E. 1990, ApJ 353, 570

Vogel, S.N. 1994, in Astronomy with Millimeter and Submillimeter Wave Interferometry, eds.M. Ishiguro & Wm.J.Welch (San Francisco, BookCrafters), 176

Vogel, S.N., Genzel, R., & Palmer, P. 1987, ApJ, 316, 243

Welch,W.J. 1993, in Massive Stars: Their Lives in the ISM, eds. J.P. Cassinelli & E. Churchwell () 15

Williams, R.J.R., Dyson, J.E., & Redman, M.P. 1996, MNRAS, 280, 667

Wilner, D.J., Welch, W.J., & Forster, J.R. 1995, ApJ, 449, L73

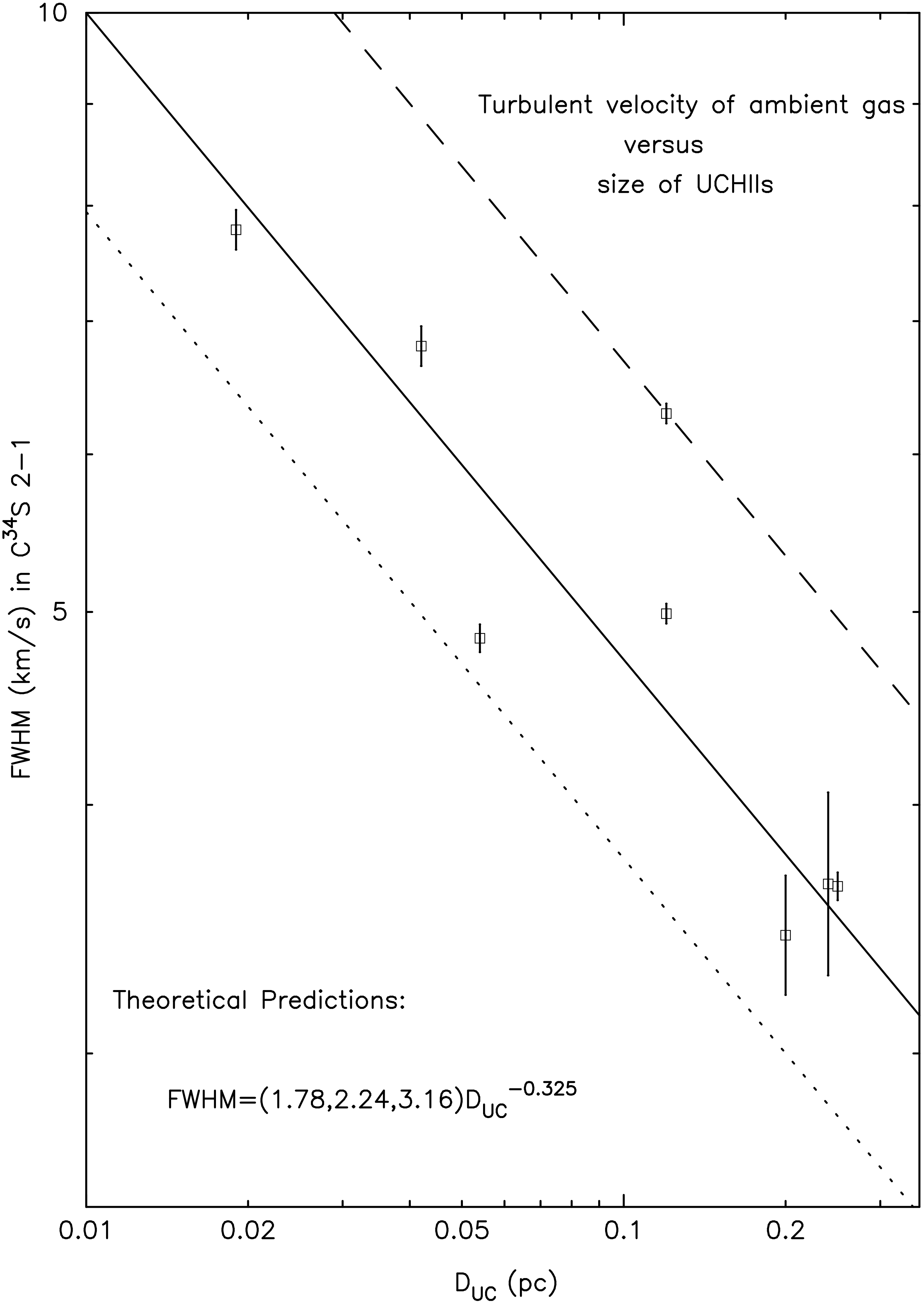
Wood, D.O.S., & Churchwell, E. 1989, ApJS, 69, 831 (WC89)

Xie, T., Hofner, P., Mundy, L., & Vogel, S. 1996, in preparation

Yorke, H.W., Tenorio-Tagle, G., & Bodenheimer, P. 1983, AA, 127, 313

Figure Caption

Figure 1 shows the theoretically expected linewidth-size relationship versus the $C^{34}S$ $J = 2 - 1$ data from the survey by Cesaroni et al (1991). Despite a large scatter, the data are remarkably consistent with the theoretical predictions for reasonable parameters, as discussed in the text.



Turbulent velocity of ambient gas
versus
size of UCHIIs
Theoretical Predictions:
FWHM=(1.78,2.24,3.16)$D_{UC}^{-0.325}$
FWHM (km/s) in $C^{34}S$ 2−1
D_{UC} (pc)
10
5
0.01
0.02
0.05
0.1
0.2